Highway Traffic Noise Measurements and Instrumentation

California Department of Transportation
Division of Environmental Analysis
Noise, Vibration, and Hazardous Waste Management Office

Caltrans

Jones & Stokes

Introduction

- Course in measurements methods and instrumentation used to measure highway traffic noise.

Purpose

The purpose of this course is to teach students:

- the types of equipment used to measure traffic noise
- fundamentals of equipment operation
- methods for collecting data in the field
- This is not a course on how to operate specific types of equipment. Equipment specific training is typically provided by the equipment manufacturer.

Assumptions Regarding Students Experience

This course assumes that students have:

- Completed Caltrans Training Module 1 - Fundamentals of Highway Traffic Noise
- An understanding of fundamental principles of acoustics (decibels, decibel addition, A-weighting, Leq, attenuation over distance, effects of barriers)
- Functional knowledge of algebra, geometry, trigonometry, and logarithms.

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Summary of Course Topics

- Purposes of noise measurements
- Instrumentation
- Noise measurement procedures
- Meteorological constraints
- Measurement locations
- Measurement time, duration, and number of repetitions

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Purposes of Noise Measurements

There are five primary reasons for taking field noise measurements:

- Determine existing ambient and background noise levels
- Calibrate noise prediction models
- Monitor construction noise levels
- Evaluate the effectiveness of abatement measures
- Perform special studies and research

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Ambient and Background Noise Levels

- Ambient noise levels are all-encompassing noise levels at a given location and time and are usually a composite of sounds from all sources including sources of specific interest
- Background noise is the total of all noise in a specific region without the presence of noise sources of interest

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Ambient and Background Noise Levels

Ambient noise levels are typically measured for the following reasons:

- To use as a baseline for comparison to future conditions
- To prioritize retrofit noise barriers
- To investigate traffic or construction noise complaints

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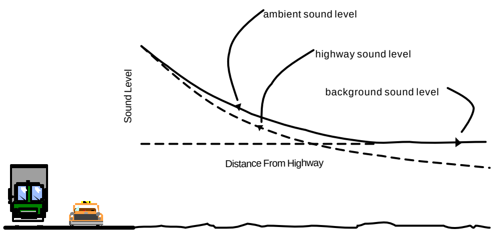
Ambient and Background Noise Levels

- Background noise levels characterize noise within the community without noise from the highway of interest.
- Sources of background noise include traffic from surface streets, mechanical equipment, trains, airplanes, etc.

Ambient and Background Noise Levels



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Model Calibration

- Measurements are taken near highways to compare measured results to modeled results.
- Calculated results are modeled using traffic data measured during the noise measurements
- Differences between measured and modeled sound levels can then be applied to calculated future noise levels if appropriate.

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Construction Noise Levels

- Measurements are taken to check contractors compliance with standard specifications or to evaluate complaints from the public

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Performance of Abatement Measures

- Measurements are taken before and after the implementation of abatement measures to evaluate the performance of the measures.
- Measurements should be conducted in accordance with appropriate applicable standards
- American National Standards Institute Standard S12.8 "Determination of Insertion Loss of Outdoor Noise Barriers".

Special Studies and Research

- Special studies and research are typically done by contractors outside of Caltrans
- Examples include research on pavement noise, effects of barrier reflections, effects of the ground surface between sources and receivers.

Instrumentation

Instruments used to characterize noise conditions include:

- Sound level meters
- Recording devices
- Frequency analyzers
- Acoustical calibrators
- Meteorological and other non-noise related equipment

Sound Level Meters

- A sound level meter (SLM) is a device that measures sound pressure levels in decibels (dB)
- The American National Standards Institute (ANSI) has established standards for SLM accuracy:
  - ANSI S1.4-1983 (Revision of S1.4 1973)
  - ANSI S1.4N -1985 (Amendment to S1.4-1983)

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Sound Level Meters

Images courtesy of **Larson Davis Laboratories**

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Sound Level Meters

- Types of meters as defined in the ANSI standard:
  - Type 0 - Laboratory grade
  - Type 1 - Precision (field use)
  - Type 2 - General purpose (field use)

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Sound Level Meters

- Basic components and features:
  - *acoustic transducer* (i.e. microphone and preamplifier) converts acoustic pressure fluctuations into an analogous electrical signal
  - *amplifier* conditions and filters the electrical signal
  - *A, B, and C weighting filters* attenuate or amplify specific frequencies as specified in the weighting curves.

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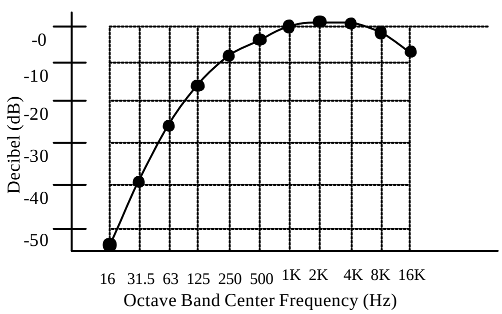
A-Weighting Network



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Sound Level Meters

- Basic components and features:
  - *detectors* detect root-mean-squared (RMS) pressure values or peak values

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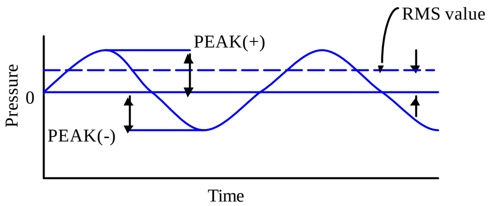
Sound Level Meters



Root-mean-square (RMS) value = 0.7 X peak value

Sound Level Meters

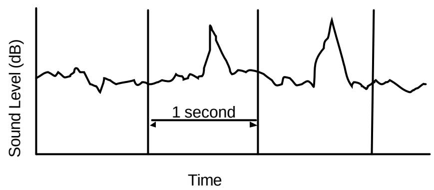
- Basic components and features:
  - *displays* - Older SLMs use an analog display which is a pointer (i.e. a needle) that moves against a calibrated scale to indicate the measured sound level. Contemporary SLMs use a digital display that shows the measured sound level and other sound level metrics (if available).

Sound Level Meters

- Basic components and features:
  - *Averaging time*. Sound meter displays typically have three types of averaging available:
    slow
    fast
    impulse
  - *Peak Pressure Level*

Sound Level Meters

- Slow (1 second averaging time)
- Fast (1/8 second averaging time)
- Impulsive (1/30 second averaging time)
- Peak Pressure Level (instantaneous peak)



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Sound Level Meters

- Basic components and features:
  - *Windscreens.* Wind can cause turbulence near the microphone that generates noise. A windscreen moves that turbulence away from the microphone so that the noise is attenuated by the time it reaches the microphone.

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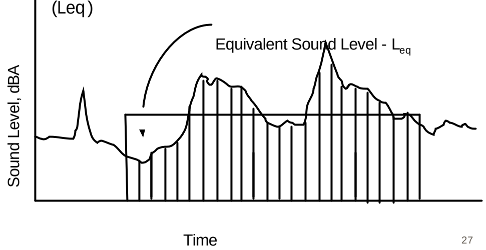
Sound Level Meters

- Additional components and features:
  - integration to produce equivalent sound level (Leq)



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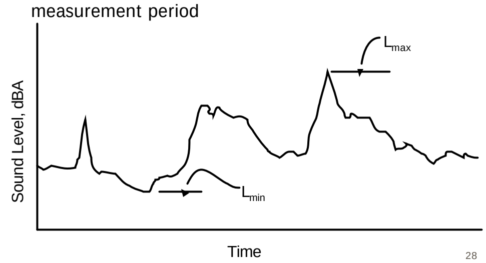
Sound Level Meters

- Additional components and features:
  - capture of Lmin and Lmax values during the measurement period



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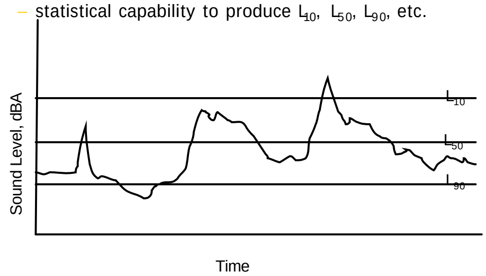
Sound Level Meters

- Additional components and features:
  - statistical capability to produce L_{10}, L_{50}, L_{90}, etc.



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Sound Level Meters

- Additional components and features:
  - data logging via an internal microprocessor to retain statistics, Leq, Lmax, Lmin over the measurement period or multiple interval periods.
  - capability to download logged data to a computer.
  - analog output for connection to a recording device

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Recording Devices

- Microprocessors - A microprocessor sometimes included in the SLM or a separate computer attached directly to the SLM can be used to record and analyze data from the SLM. Data collected and be exported into a spreadsheet for subsequent evaluation.

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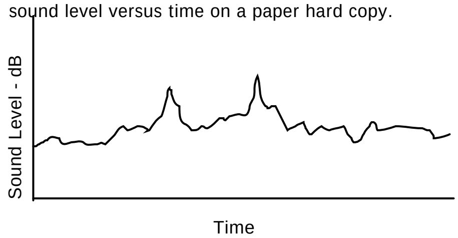
Recording Devices

- Graphic level recorder - Provides a plot of instantaneous sound level versus time on a paper hard copy.



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Recording Devices

- Audio recorders - Analog output from the SLM is connected to the analog input of an audio recorder.
- Types of recorders include:
  - analog reel-to-reel tape recorders,
  - analog cassette tape recorders,
  - FM (frequency modulation) reel-to-reel tape recorders,
  - Digital audio tape (DAT) recorders, and
  - Computer with audio recording software.

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Recording Devices

Images from **Nagra Electronics and Sony Corporation**

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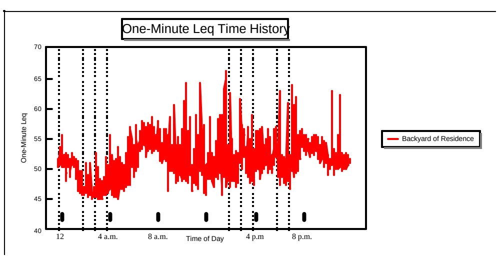
Recording Devices



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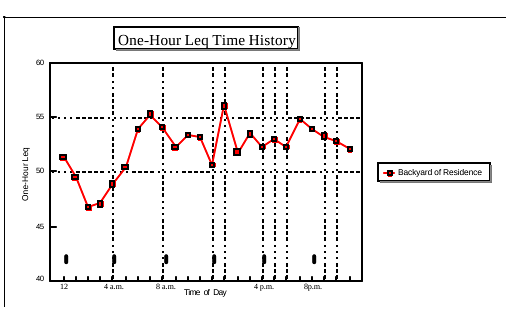
Recording Devices



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Frequency Analyzers

- Real Time Analyzers - RTAs use analog or digital filters to decompose an audio signal into 1/3 octave or octave band frequency components, i.e. frequency spectra . The term *real time* refers to the processing and display of a continuously changing sound spectra.

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Frequency Analyzers

Image from Brüel & Kjær

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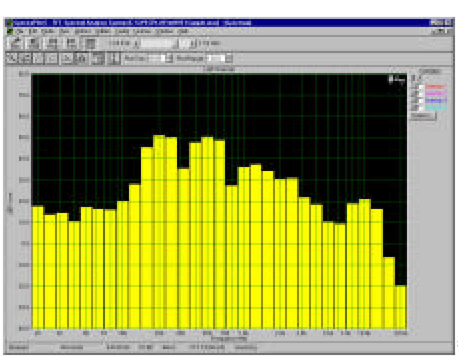
Frequency Analyzers



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Frequency Analyzers

- Fast Fourier Transform (FFT) Analyzers - FFTs use mathematical equations to construct a continuous narrow band frequency spectrum with constant bandwidth resolution.

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Frequency Analyzers

Image from Brüel & Kjær

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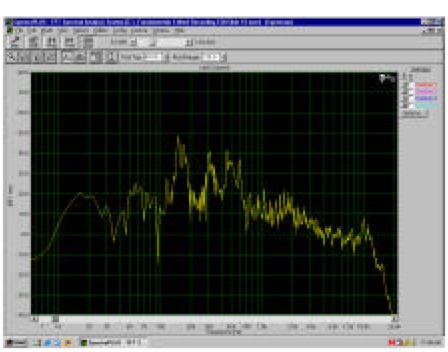
Frequency Analyzers



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Acoustical Calibrators

- Acoustical Calibrator - This is a device that produces a known, stable sound pressure level at the diaphragm of a microphone that is inserted into the cavity of the calibrator. Calibrators are used to calibrate SLMs in the field.
- There are two types of acoustical calibrators:
  - pistonphone - produces a sound pressure level by means of a moving piston.
  - loudspeaker type - produces a sound pressure level by means of a small loudspeaker.

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Acoustical Calibrators

Image from **Larson Davis Laboratories**

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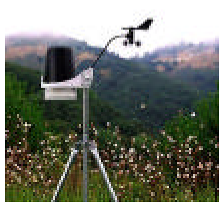
Meteorological Equipment

- Meteorological equipment
  - anemometer which measures wind speed to the nearest mile per hour to at least 15 mph and direction to the nearest 22 1/2 degrees (16 point compass)
  - thermometer
  - relative humidity sensor



Images from **Kestrel Wind/Weather Instruments** and **Davis Instruments**

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Accessory Equipment

- Other non-noise-related equipment is useful in the field:

tape measure	tripods
laser range finder	equipment cases
survey levels	duct tape
walkie-talkies	video camera
traffic counters	film or digital camera
hard hat	survey rod
orange vests	GPS unit
orange safety cones	

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Noise Measurement Procedures

- General procedures for field noise measurements include:
  - Instrument setup
  - Field calibration
  - Measurements
  - Documentation

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Instrument Setup

- Instrument setup
  - Place SLM 5 feet above the ground and at least 10 feet from reflecting surfaces such as buildings, walls, parked vehicles, billboards, etc.
  - Operator should avoid shielding the SLM with their body.
  - Place thermometer in the shade.
  - Anemometer should have good exposure to wind.

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Field Calibration

- Acoustical calibrators are used to calibrate the SLM in the field.
- Calibrators typically produce a reference sound pressure level of 94 or 114 dB. Use the level specified for the SLM.
- Use the following field calibration procedure:
  - Allow the SLM to warm-up at least one minute or as specified by the equipment manufacturer
  - Carefully place the calibrator over the microphone and make sure that it is property seated.
  - Avoid touching the calibrator during calibration
  - Check or adjust calibration as specified by the manufacturer

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Field Calibration

- SLM should be calibrated before and after each measurement.
- If several measurements are made during one setup calibration may be checked between measurements.
- For routine measurements calibration should be within 0.5 dB of the reference level. If the SLM is out of calibration by more than 0.5 dB, adjust calibration.

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Field Calibration

- Measurements should be adjusted based on the initial and final calibration values.
- Example:
  - Calibrator reference value = 94.2 dB
  - Initial calibration = 94.4 dB
  - Final calibration = 94.6 dB

Adjustment = 94.2 -[(94.4 + 94.6/2)] = -0.3 dB

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Measurements

- Following calibration place the SLM at the measurement location.
- Set the SLM to A -weighted sound levels.
- Start the SLM. Pause the measurement for barking dogs, lawn mowers, aircraft overflights.
- Avoid talking during the measurements. If approached by curious neighbors, pause the meter.
- For highway noise studies simultaneous traffic counts should be taken. Directional traffic should be counted separately segregated into autos, medium trucks, and heavy trucks.

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Measurements

- Stop the SLM at the end the measurement session.
- Log:
  - Leq
  - Lmax
  - Lmin
  - Lxx
  - measurement duration
  - wind speed and direction
  - temperature
  - humidity
  - sky conditions (Cloud Cover Class)

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Documentation

- Create blank forms for logging field data. Forms can be designed for the specific investigation.
- Data to be recorded includes information on:
  - noise measurements sites
  - noise measurements
  - meteorological conditions
  - traffic counts

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Documentation

- Noise measurement sites
  - Record where the measurement was taken. Use aerial photographs and plan drawings to indicate locations.
  - Show enough information to enable someone else reproduce the measurement position at a later date. A photo of the site can be useful in this regard.
  - Record microphone location relative to natural or artificial land marks.
  - Show distances to buildings, curbs, trees, etc. Indicate the microphone position within one foot horizontally and .5 foot vertically.

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Documentation

- Noise Measurement Sites
  - Record information on instruments used, i.e. manufacturers, model number, and serial number.
  - Record operators names.
  - Record before and after calibration information
  - Record site number, date, time, length of measurement, and sound level data i.e. Leq, Lmax, Lmin, Lx.
  - Note information on contamination or anything else that may effect the measurement results.

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Documentation

- Meteorological conditions
  - Record the direction and speed of the prevailing wind, temperature, relative humidity, and sky conditions.
  - Classify sky conditions as follows:

Class 1 - heavily overcast
Class 2 - lightly overcast (either with continuous sun or the sun obscured intermittently by clouds 20 to 80% of the time)
Class 3 - Sunny (sun essentially unobscured by clouds at least 80% of the time
Class 4 - Clear night (less than 50% cloud cover)
Class 5 - Overcast night (50% or more cloud cover)

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Meteorological Constraints on Noise Measurements

- Wind speeds over 5 m/s (11 mph) may begin to contaminate noise measurements
- Extremes in temperature and humidity can effect critical components of SLMs. For example during high humidity condensation can form on microphone diaphragm and cause popping
- Rain or snow on highway pavement alters the level and frequency content of tire noise
- Refraction caused by wind shear or temperature gradients will alter noise levels

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Meteorological Criteria

- Noise measurements should not be taken when one or more or the following conditions exists:
  - Wind speeds of more than 5 m/s (11 mph)
  - Manufacturers recommendations for acceptable temperature and humidity ranges for equipment are exceeded. Typically these ranges are from 14 to 122 degrees F and 5% to 90% relative humidity
  - Rain, snow, or wet pavement conditions

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Equivalent Meteorology Conditions

- When measurements taken at two different times are to be compared, the measurements must be taken under equivalent meteorological conditions. A typical situation would be “before and after” measurements of sound walls. Conditions to be considered include:
  - wind
  - temperature
  - cloud cover
  - humidity

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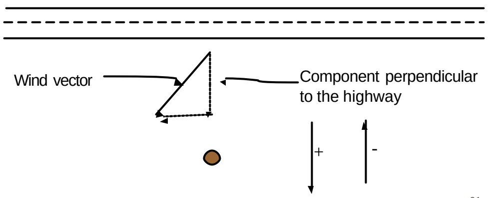
Equivalent Meteorology Conditions

- Equivalent wind conditions
  - Equivalency of wind conditions is based on the vector component perpendicular to the highway between the highway and the receiver.



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Equivalent Meteorology Conditions

- Equivalent wind conditions
  - Wind conditions are equivalent if the wind class remains unchanged AND the vector components of average wind velocity perpendicular to the highway do not differ by more than a certain limit.

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Equivalent Meteorology Conditions

Classes of Wind Conditions

Wind Class	Vector Component of Wind Velocity, m/s (mph)
Upwind	-1 to -5 (-2.2 to -11)
Calm	-1 to +1 (-2.2 to +2.2)
Downwind	+1 to +5 (+2.2 to +11)

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Equivalent Meteorology Conditions

- Wind equivalency limits
  - To keep accuracy within plus/minus 1 dB for measurements within 70 meters (230 feet) of the highway, the difference limit is 1 m/s second (2.2 mph)
  - The difference limit does not apply to calm conditions

Equivalent Meteorology Conditions

Examples:

- Are wind speeds of 3 mph and 5 mph equivalent?
- Yes, both are in the same class and the difference is less than 2.2 mph.

- Are wind speeds of 1 mph and 3 mph equivalent?
- No, speed class changes from calm to downwind.

Equivalent Meteorology Conditions

Examples:

- Are wind speeds of -3 mph and -6 mph equivalent?
- No, although both are in the same wind class the two speed differ by 3 mph which is greater than 2.2 mph.

- Are wind speeds of -2 mph and 2 mph equivalent?
- Yes, both are in the calm wind class. The difference is greater than 2.2 mph but the difference criteria does not apply to the calm wind class.

Equivalent Meteorology Conditions

- Equivalent wind conditions
  - wind speed and direction should be sampled throughout the noise monitoring session and averaged.

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Equivalent Meteorology Conditions

- Equivalent temperature and cloud cover
  - Measurements should be made for the same class of cloud cover.
  - Temperatures should be within 25 degrees F of each other.
- Equivalent humidity
  - There are no strict guidelines for the equivalence of humidity.
  - Try to take measurements under similar humidity conditions, I.e. avoid comparing measurements taken under extremely dry conditions (e.g. < 25%) with those made during humid conditions (>75%).

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Quality Assurance

- SLMs should be calibrated at the factory or by an accredited laboratory at the interval recommended by the manufacturer, typically annually.
- All calibrations should be traceable to the National Institute of Standards and Technology in Washington, D.C.

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Measurement Locations

- Selection of measurement locations requires planning and foresight.
- A balance between the quantity of the locations and the cost in person hours must be made.
- Use all available tools to select quality monitoring locations:
  - project layout mapping,
  - aerial photographs,
  - cross sections,
  - topographic maps

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General Site Recommendations

- Sites should be clear of major obstructions between the source and the receiver unless these obstructions are representative of the area of interest.
- Sites must be free of noise contamination by sources other than those of interest (i.e. lawn mowers, pool pumps, air conditioners).
- Sites should be acoustically representative of areas of interest and must be located at or represent locations of frequent human use.
- Meteorological conditions must not be outside the limits discussed above.

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Measurement Site Selection

- Receivers are locations of interest in the noise study area. Typically, they are residential areas but can include other noise sensitive uses.
- Noise measurement sites are locations where noise levels are measured.
- Not all receivers are noise measurement sites. A noise measurement site will typically represent one or more receivers.
- In some cases access or other restrictions preclude taking measurements at a specific receiver location. Measurements are then often taken at an acoustically equivalent site.

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Site Selection by Purpose of Measurement

- Noise measurement sites should be selected according to the purpose of the measurement
  - For assessing impacts of a new highway project, locations should be selected in areas that will be exposed to the highest noise levels generated by the highway after completion of the project
  - For assessing background community noise levels, sites should be selected in areas that represent noise from the community without influence from the highway.

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Site Selection by Purpose of Measurement

- Noise measurement sites should be selected according to the purpose of the measurement:
  - For classroom measurements or other interior measurements, measurements should be taken in rooms with worst noise exposure from the highway.
  - Measurements should be taken at locations where people would be impacted (i.e. desk, chairs, and beds).
  - Avoid measurements within 3 to 4 feet of a wall
  - If windows are normally open take measurements with windows open and closed
  - Fans, clocks, appliances, etc. should be turned off.
  - People should vacate the room or be very quiet.

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Site Selection by Purpose of Measurement

- Noise measurement sites should be selected according to the purpose of the measurement:
  - Model calibration measurements should be taken near the highway and should only include noise from the highway (i.e pause measurements during noise events not from traffic on the highway)
  - Locations for construction noise monitoring are dictated by standard specifications, special provision or local ordinances which specify the distance and metric to be used
  - Special studies, research projects and before-and-after measurements require detailed design of measurement locations.

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Site Selection by Acoustical Equivalence

- Sites are acoustically equivalent if they are:
  - generally the same distance from the highway,
  - have the same degree of shielding from the highway,
  - are at the same elevation relative to the highway,
  - have the similar intervening ground absorption.
- Measurements are not taken at every potentially effected receiver, rather regions under study are usually subdivided into subregions that have acoustical equivalence.

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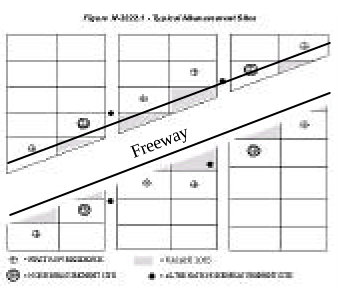
Site Selection by Acoustical Equivalence



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Site Selection by Geometry

- Site topography (i.e. site geometry) plays an important role in site selection.
- Sometimes based on geometry receivers located farther from a highway are exposed to higher noise levels than those located closer.

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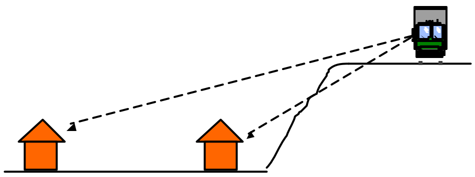
Site Selection by Geometry



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Measuring Times, Duration, and Number of Repetitions

- The time during the day that measurements are taken, the duration of the measurements and the number of measurement repetitions effect the accuracy of the measurements.

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Measuring Times

- FHWA 23 CFR Part 772 requires that traffic characteristics that yield the worst hourly traffic noise impact on a regular basis be used for predicting noise levels and assessing impacts.
- Sometimes weekly or seasonal variations must be taken into consideration.

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Noisiest Hour for Highway Traffic

- The peak traffic hour is generally not the noisiest hour of the day.
- During rush hour traffic speeds can be reduced and heavy truck volumes are often low.
- Free flow conditions before and after rush hours often yield higher noise levels.

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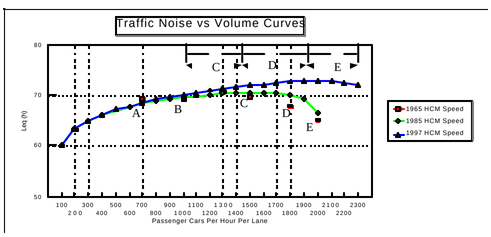
Noisiest Hour for Highway Traffic



Indicates that maximum noise occurs at LOS D-E at 85% of capacity and 100% of free flow speed.

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Noisiest Hour for Highway Traffic

- How do we identify the noisiest hour?
  - Get 24 -hour traffic counts to get a feel for when the peak traffic periods are. Take preliminary sample measurements throughout the day or before, during, and after the peak traffic periods.
  - Place the meter out for 24-hours or several days to determine when the noisiest hour is. Be careful to avoid contamination of data collected when the meter is unattended. If the data is consistent over several days, the likelihood for contamination is low.

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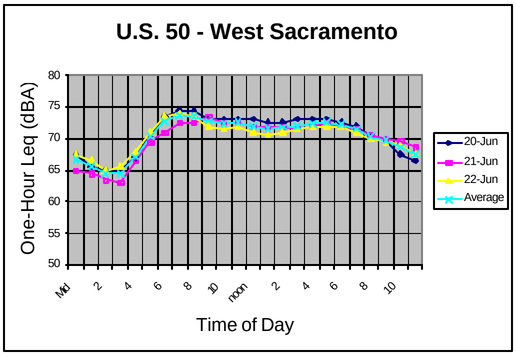

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Adjusting Other-Than-Noisiest Hour

- Ideally, traffic noise measurements should be taken during the noisiest hour of the day.
- From a practical perspective highway traffic noise measurements cannot always be taken during the noisiest hour.
- Measurements taken during other-than-noisiest hours need to be adjusted.
- There are two approaches to doing this.

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Adjusting Other-Than-Noisiest Hour

- Adjustment Approach 1
  - Take a sound level measurement and count and classify vehicles during the measurement.
  - Scale traffic data up to one hour, i.e if sound measurements and counts were taken for 15 minutes, multiply counts by 4.
  - Input the scaled volume into the model and run the model.
  - Input volumes and speeds associated with the noisiest hour into the model.
  - Subtract model result from measurements from the noisiest hour result.
  - Add the difference to the measured level.

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Adjusting Other-Than-Noisiest Hour

- Adjustment Approach 1 - Example
  - Measured noise level = 66 dBA
  - Calculated noise levels based on measurement counts = 67 dBA
  - Calculated noise level with noisiest hour data = 69 dBA
  - Difference in calculated values: 69-67 = 2 dB
  - Adjusted measured level: 66 dB + 2 dB = 68 dBA

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Adjusting Other-Than-Noisiest Hour

- Adjustment Approach 2
  - Use data from 24-hour measurement to determine the difference between noisiest hour and measured hour.

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Adjusting Other-Than-Noisiest Hour

Hour	Average	Difference (re: loudest hour)
midnight	67	-7
	66	-8
	65	-9
	65	-9
4:00 a.m.	67	-7
	70	-3
	73	-1
	74	0
8 a.m.	74	0
	73	-1
	72	-1
	73	-1
noon	72	-2
	72	-2
	72	-2
	72	-2
4:00 p.m.	72	-1
	73	-1
	72	-2
	72	-2
8 p.m.	70	-3
	70	-4
	69	-5
	68	-6

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Measurement Duration

- Measurements do not need to be taken for an entire hour.
- The length of measurements depends on how much noise level fluctuate.
- Fluctuation in sound levels is a function of traffic density. The higher the density the lower the fluctuation.
- The greater the fluctuation the longer the measurement should be.
- Generally continue measurements until the range in Leq fluctuations is less than 0.5 dBA.

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Measurement Duration

- Suggested Measurement Durations:

Traffic Volume	Vehicle Per Hour Per Lane	Duration
High	>1,000	10 min.
Medium	500 to 1,000	15 to 20 min.
Low	<500	20 to 30 min.

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Number of Repetitions

- Multiple measurements at a specific site tend to vary for the following reasons:
  - changes in traffic volumes, speeds, and/or mixes.
  - contamination from other sources, such as barking dogs, aircraft, nearby construction.
  - changes in meteorology.
  - changes in site conditions
  - instrument error
  - operator error
  - calibration error
  - equipment malfunction

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Number of Repetitions

- TENS strongly recommends that measurements be repeated at least once at each site.
- An exception to this are when three or more measurements are made in the same general area or in relatively rapid succession.
- The recommended minimum number of measurements should be taken with different setups (i.e. power turned off and equipment calibration re -checked) and under similar traffic and meteorological conditions.
- If measurements don't agree, further repetitions will be necessary.

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Number of Repetitions

- For routine situations, multiple measurements at the same site normalized for differences in traffic mix and volumes should agree as follows:
  - Measurements for 2 setups should agree within 2 dB
  - If more than one measurements is taken per setup, the mean of the two setups should agree within 2 dB
  - Repetitive measurements for each setup should be within +/- 1 dB of the mean noise level of the setup.

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Number of Repetitions

- Examples:

Setup 1 = 75.5 dBA	Setup 2 = 76.5 dBA	OK
Setup 1 = 75.4 dBA	Setup 2 = 77.6 dBA	Not OK

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Number of Repetitions

Measurement 1	Setup 1 = 69 dBA	Setup 2 = 71 dBA
Measurement 2	Setup 1 = 67 dBA	Setup 2 = 69 dBA
Mean	Setup 1 = 68 dBA	Setup 2 = 70 dBA
Mean of all	69 dBA	

Means of setups are within 2 dB,
Individual setups are with 1 dB of setup mean.

Therefore, the measurements are OK.

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- Before applying the comparison criteria discussed above repeated noise level measurements must be adjusted or normalized.
- A detailed approach or a simple normalizing method can be used.

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- Detailed Method - Traffic volumes and speeds for each measurement are input into a noise prediction model. Model results are compared to the initial measurement to determine normalizing values for each subsequent measurement.

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- Detailed method example:

Measurement	Measured Value	Modeled Value	Normalizing Value	Normalized Value
1	66.4 dBA	66.9	0 dB	66.4 dBA
2	68.2 dBA	67.4	-.5 dB	67.7 dBA
3	65.8 dBA	66.2	.7 dB	66.5 dBA
4	68.5 dBA	68.4	-1.5 dB	67.0 dBA
			Mean =	66.9 dBA

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- Simple method - This approach can be used in the field to check measurements. The normalizing value is determined based on ratios of equivalent vehicles (V_E).
- The simple method cannot be used when:
  - average traffic speeds are not the same for each measurement
  - truck speeds are significantly different (more than 5 mph) from auto speeds
  - receivers are close to the freeways (typically closer than 45 feet)
  - the directional split of traffic is different by more than 20% for each vehicle group between measurements.
  - barriers or terrain are located between highway and the receiver

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- This method uses the concept of equivalent vehicles (V_E) to equate the number of medium truck and heavy trucks to an acoustically equivalent number of autos.
- Based on California Reference Energy Mean Emission Levels:

  one heavy truck at 55 mph ~ 13 autos

  one medium truck at 55 mph ~ 5 autos
- Convert heavy trucks and medium trucks to an equivalent number of automobiles

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

*Table N-3340.1 - Equivalent Vehicles Based on Calveno REMELs**

	NUMBER OF EQUIVALENT VEHICLES		
Speed, km/h (Mph)	1 Heavy Truck =	1 Medium Truck =	1 Automobile =
56 (35)	30.9	9.4	1
64 (40)	24.1	7.8	1
72 (45)	19.0	6.7	1
80 (50)	15.3	5.8	1
88.5 (55)	12.8	5.1	1
97 (60)	10.9	4.7	1
105 (65)	9.5	4.3	1

*Based on California Vehicle Noise Reference Energy Mean Emission Levels and vehicle definitions in FHWA-RD-77-108 (Also see sections N-4400 and N-5510)

Normalizing Measurements for Differences in Traffic Mixes and Volumes

*Table N-3340.2 - Equivalent Vehicles Based on TNM REMELs***

	NUMBER OF EQUIVALENT VEHICLES		
Speed, km/h (mph)	1 Heavy Truck =	1 Medium Truck	1 Automobile =
56 (35)	19.1	7.1	1
64 (40)	15.1	5.8	1
72 (45)	12.9	5.0	1
80 (50)	11.5	4.5	1
88.5 (55)	10.4	4.1	1
97 (60)	9.6	3.7	1
105 (65)	8.9	3.5	1
113 (70)	8.3	3.2	1

**Based on FHWA Traffic Noise Model (TNM) Reference Energy Mean Emission Levels and vehicle definitions in FHWA-PD-96-008, DOT-VNTSC-FHWA-96-2 (Also see sections N-4400 and N-5520)

Normalizing Measurements for Differences in Traffic Mixes and Volumes

- Example: Convert the following number of vehicles travelling at 65 mph in a 15 minute period to an equivalent number of vehicles. Use Calveno REMELS:

789 autos,34 medium trucks, 76 heavy trucks

autos = 789 x 1 = 789
MT = 34 x 4.3 = 146
HT = 76 x 9.5 = 722

Total equivalent vehicles V_E = 1,657

Normalizing Measurements for Differences in Traffic Mixes and Volumes

Example: Three sets of measurements were taken at a single location. Determine if they meet the agreement criteria using Calveno emission rates.

Meas. No.	Setup No.	15 min L_{eq} (dBA)	Heavy Trucks	Medium Trucks	Autos	Speed (mph)	Equivalent Vehicles (VE)
1	1	74.4	100	50	1275	55	[illegible]
2	1	75.5	150	100	850	55	[illegible]
3	2	74.0	60	30	1700	55	[illegible]

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

Convert the medium and heavy trucks to equivalent autos.

Meas. No.	Setup No.	15 min L_{eq} (dBA)	Heavy Trucks	Medium Trucks	Autos	Speed (mph)	Equivalent Vehicles (VE)
1	1	74.4	100	50	1275	55	2810
2	1	75.5	150	100	850	55	3280
3	2	74.0	60	30	1700	55	2621

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- Use the first measurement as the reference measurement.
- The number of equivalent vehicles for Measurement 2 is higher than Measurement 1 so the noise level for Measurement 2 needs to scaled down for comparison to Measurement 1:

$$10 \log (2810/3280) = -0.7 \text{ dB}$$

Measurement 2 normalized $= M_{2N} = 75.5 - 0.7 = 74.8$ dBA

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- The number of equivalent vehicles for Measurement 3 is lower than Measurement 1 so the noise level for Measurement 3 needs to scaled up for comparison to Measurement 1:

  10 log (2810/2621) = 0.3 dB

  Measurement 3 normalized = M_{3N} = 74.0 + 0.3 = 74.3 dBA

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Normalizing Measurements for Differences in Traffic Mixes and Volumes

- Summary of results:

Measurement Number	Setup Number	Normalized L_{eq}
1	1	74.4
2	1	74.8
3	2	74.3

Measurements are OK!

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Classroom Noise Measurements

- In determining a projects traffic noise effects on a classroom interior, simultaneous measurements inside and outside the building must be made.
- When the project involves reconstruction of an existing freeway, simultaneous measurements may be taken inside and outside the classroom.
- Inside the measurement should be taken in the center of the room. If there is no air-conditioning measurements should be taken with windows open and closed.

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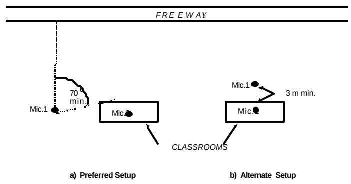
Classroom Noise Measurements

- Measurement setup for reconstruction next to an existing freeway.

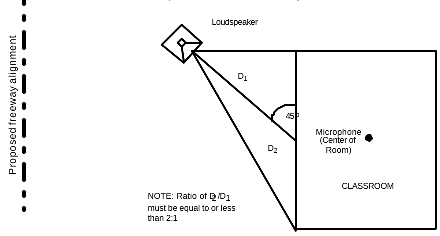


Classroom Noise Measurements

- For a new alignment, the noise reduction provided by the school building shell must be directly measured.
- Use a recording of traffic noise or an electronically generated noise spectrum. Measurements taken inside and outside the building are then compared to determine the noise reduction.
- Amplification should be at least 10 dBA above the background sound level both inside and outside the building.

Classroom Noise Measurements

- Measurement setup for a new alignment



Concluding Remarks

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